

# Concrete Damage—Plasticity Material Tests

## Introduction

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This example shows the behavior of the coupled damage–plasticity model for concrete when subjected to different loading conditions. Several material tests that are commonly used to characterize concrete are set up for this purpose

For details on the coupled damage–plasticity material model, see the section *Coupled Damage–Plasticity* in the *Structural Mechanics Module User’s Guide*, and [Ref. 1](#) and [Ref. 2](#).

## Model Definition

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The **Test material** feature is used to test the material model when subjected to different loading conditions. Hence no specific geometry is required for the base component of the model. Concrete is, however, a so-called quasibrittle material which means that its response is size dependent, especially in tension. The size of the test specimen used by **Test material** is therefore important for the tests to give representative results. Here a characteristic size of 0.1 m is used.

In total six different tests are set up:

- 1 Uniaxial compression
- 2 Uniaxial tension
- 3 Biaxial compression, with a biaxiality ratio of 0.5
- 4 Isotropic (triaxial) compression
- 5 Uniaxial cyclic loading (tension to compression to tension)
- 6 Uniaxial cyclic loading (compression to tension)

A generic set of material properties are used for the concrete, (see [Table 1](#)), but the model can be used to verify the model response for other properties as well. Note that these material properties are sufficient to define the model parameters of the coupled damage–plasticity model, but there are many more parameters available to modify the response of the material model that are here kept equal to their default value.

TABLE 1: MATERIAL PROPERTIES OF THE CONCRETE.

Material property	Symbol	Value
Young’s modulus	$E$	25 GPa
Poisson’s ratio	$\nu$	0.2
Compressive strength	$\sigma_{uc}$	20 MPa

TABLE I: MATERIAL PROPERTIES OF THE CONCRETE.

Material property	Symbol	Value
Tensile strength	$\sigma_{ut}$	2 MPa
Fracture energy	$G_{ft}$	100 J/m <sup>2</sup>

## Results and Discussion

Figure 1 shows the results of the first two tests. The characteristic anisotropy of concrete in compression versus tension is clearly observable.

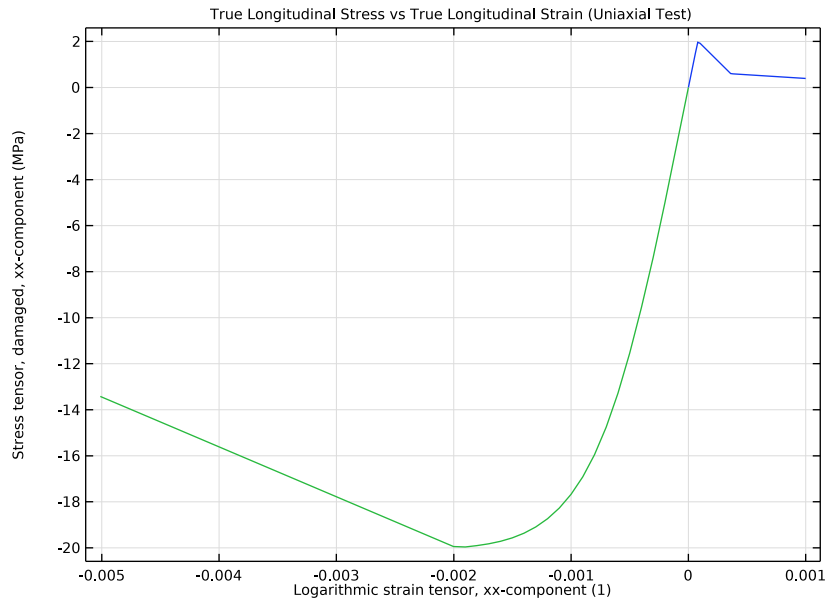
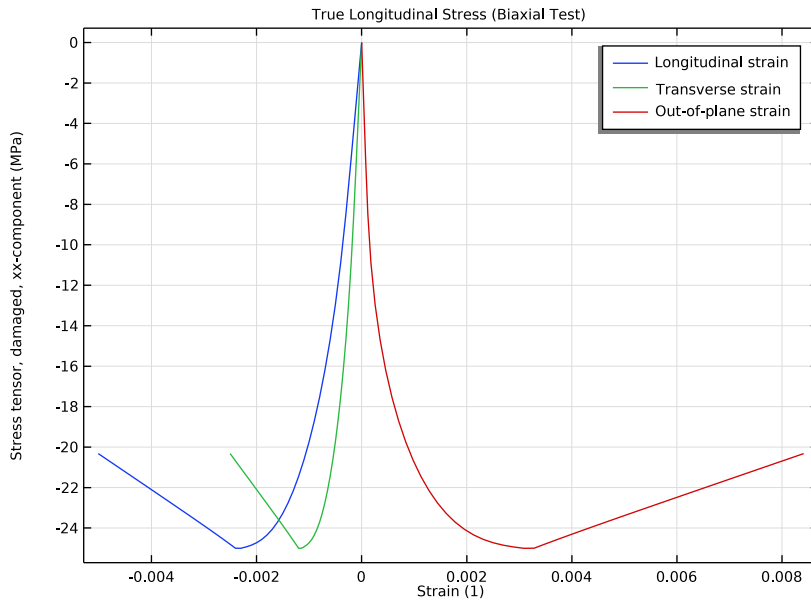


Figure 1: Stress versus strain for concrete subjected to monotonic uniaxial loading.

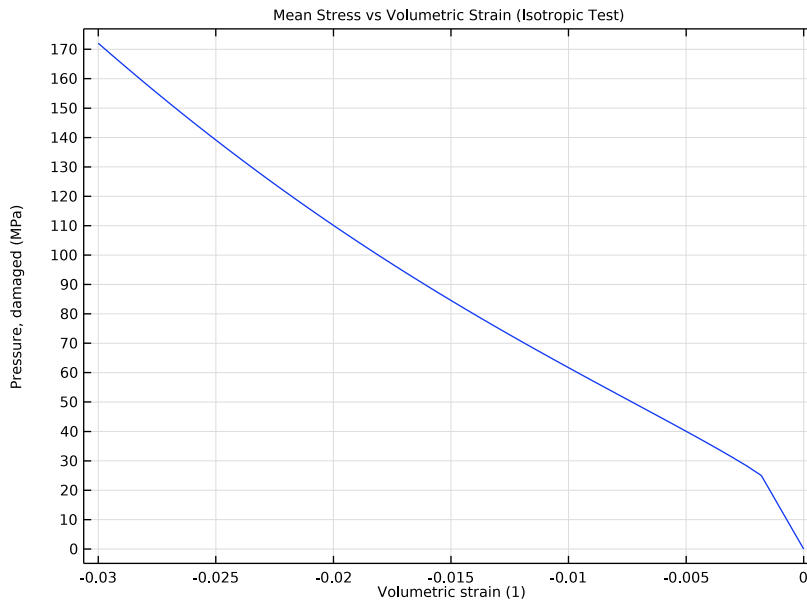
Results from the biaxial compression test are shown in [Figure 2](#), which shows the stress in the main loading direction versus all three normal components of the strain tensor.



*Figure 2: Stress versus strain for concrete subjected to monotonic biaxial compression.*

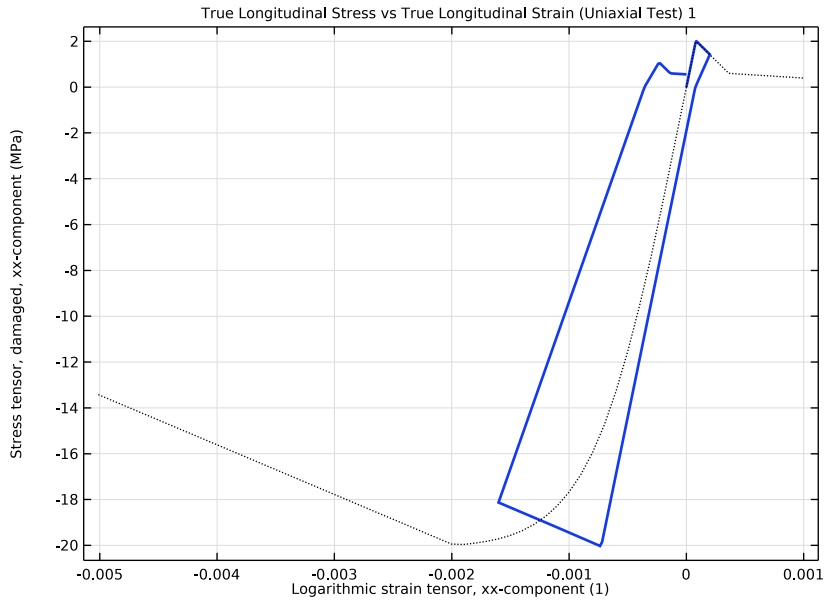
Results from the isotropic compression test are shown in [Figure 3](#), where it is clearly visible that the model response is ductile. The transition from a quasibrittle to a ductile response

as the stress state goes toward isotropic compression is an important characteristic of concrete subjected to severe loading.



*Figure 3: Stress versus strain for concrete subjected to monotonic isotropic compression.*

Figure 4 and Figure 5 show results from the two cyclic tests. It is clearly visible how the response during cyclic loading deviates from the monotonic stress versus strain curve since there is irreversible deformation. In Figure 4 one can also note that all available plastic deformation occurs when the specimen is loaded in tension and starts to crack. Hence, there is no plastic hardening when the stress is reversed to compression; instead the response is “elastic” until softening starts.



*Figure 4: Stress versus strain for concrete subjected to cyclic uniaxial loading going tension to compression and back to tension. The dotted black curve shows the stress versus strain for monotonic loading.*

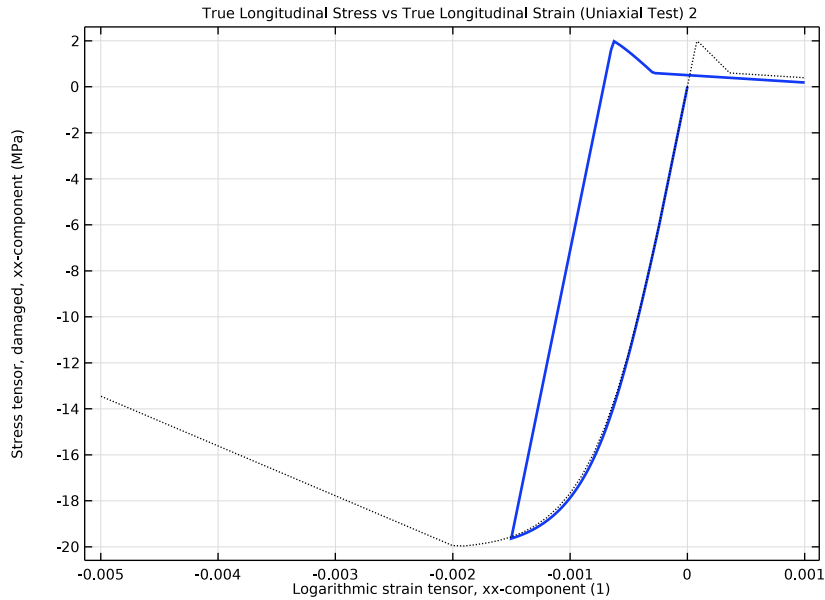


Figure 5: Stress versus strain for concrete subjected to cyclic uniaxial loading going from compression to tension. The dotted black curve shows the stress versus strain for monotonic loading.

## References

1. P. Grassl and M. Jirásek, “Damage-plastic model for concrete failure,” *Int. J. Solids Struct.*, vol. 43, pp. 7166–7196, 2006.
2. P. Grassl, D. Xenos, U. Nyström, R. Rempling, and K. Gylltoft, “CDPM2: A damage-plasticity approach to modelling the failure of concrete,” *Int. J. Solids Struct.*, vol. 50, pp. 3805–3816, 2013.

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**Application Library path:** Geomechanics\_Module/Verification\_Examples/  
concrete\_damage\_plasticity

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## Modeling Instructions

From the **File** menu, choose **New**.

## NEW


In the **New** window, click  **Model Wizard**.

## MODEL WIZARD

- 1 In the **Model Wizard** window, click  **3D**.
- 2 In the **Select Physics** tree, select **Structural Mechanics>Solid Mechanics (solid)**.
- 3 Click **Add**.
- 4 Click  **Done**.

## GEOMETRY I

*Block 1 (blk1)*


In the **Geometry** toolbar, click  **Block**.

## SOLID MECHANICS (SOLID)

*Linear Elastic Material 1*

In the **Model Builder** window, under **Component 1 (comp1)>Solid Mechanics (solid)** click **Linear Elastic Material 1**.

*Concrete 1*

- 1 In the **Physics** toolbar, click  **Attributes** and choose **Concrete**.
- 2 In the **Settings** window for **Concrete**, locate the **Concrete Model** section.
- 3 From the **Material model** list, choose **Coupled damage-plasticity**.

## ADD MATERIAL FROM LIBRARY

In the **Home** toolbar, click  **Windows** and choose **Add Material from Library**.

## ADD MATERIAL

- 1 Go to the **Add Material** window.
- 2 In the tree, select **Built-in>Concrete**.
- 3 Click **Add to Component** in the window toolbar.

## MATERIALS

*Concrete (mat1)*

- 1 In the **Settings** window for **Material**, locate the **Material Contents** section.




2 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Tensile strength	sigma <sub>t</sub>	2 [MPa]	Pa	Yield stress parameters
Compressive strength	sigma <sub>c</sub>	20 [MPa]	Pa	Yield stress parameters
Tensile fracture energy	G <sub>ft</sub>	100 [J/m <sup>2</sup> ]	J/m <sup>2</sup>	Fracture parameters

Add a number of monotonic tests for different loading conditions.

## SOLID MECHANICS (SOLID)

### Monotonic Tests

- 1 In the **Physics** toolbar, click  **Global** and choose **Test Material**.
- 2 In the **Settings** window for **Test Material**, type Monotonic Tests in the **Label** text field.
- 3 Select Domain 1 only.
- 4 Locate the **Material Tests** section. From the **Test specimen size** list, choose **User defined**.
- 5 In the  $L$  text field, type 0.1 [m].
- 6 Find the **Tests** subsection. In the  $\lambda_{\min}$  text field, type 1-5e-3.
- 7 In the  $\lambda_{\max}$  text field, type 1+1e-3.
- 8 Select the **Biaxial test** check box.
- 9 In the  $\lambda_{\min}$  text field, type 1-5e-3.
- 10 In the  $\lambda_{\max}$  text field, type 1.
- 11 In the  $\beta$  text field, type 0.5.
- 12 Select the **Isotropic test** check box.
- 13 In the  $\lambda_{\min}$  text field, type 1-1e-2.
- 14 Click **Automated Model Setup** in the upper-right corner of the **Material Tests** section.  
From the menu, choose **Set up Tests**.

## RESULTS

In the **Model Builder** window, expand the **Results** node.


### *True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test)*

In the **Model Builder** window, expand the **Results>Material Tests (Study: Monotonic Tests)** node.

#### *Point Graph 1*

- 1 In the **Model Builder** window, expand the **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test)** node, then click **Point Graph 1**.
- 2 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.
- 3 From the **Unit** list, choose **MPa**.

#### *Point Graph 2*

- 1 In the **Model Builder** window, click **Point Graph 2**.
- 2 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.
- 3 From the **Unit** list, choose **MPa**.
- 4 In the **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test)** toolbar, click  **Plot**.

#### *Point Graph 1*

- 1 In the **Model Builder** window, expand the **Results>Material Tests (Study: Monotonic Tests)>True Longitudinal Stress vs True Longitudinal Strain (Biaxial Test)** node, then click **Point Graph 1**.
- 2 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.
- 3 From the **Unit** list, choose **MPa**.
- 4 Click to expand the **Legends** section. Select the **Show legends** check box.
- 5 From the **Legends** list, choose **Manual**.
- 6 In the table, enter the following settings:

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**Legends**

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Longitudinal strain

Also plot the longitudinal stress versus the transverse and out-of-plane strain components.

- 7 Right-click **Point Graph 1** and choose **Duplicate**.

#### *Point Graph 2*

- 1 In the **Model Builder** window, click **Point Graph 2**.

- 2 In the **Settings** window for **Point Graph**, locate the **x-Axis Data** section.
- 3 In the **Expression** text field, type `solid1.e1ogy`.
- 4 Locate the **Legends** section. In the table, enter the following settings:

Legends
Transverse strain


- 5 Right-click **Point Graph 2** and choose **Duplicate**.

#### *Point Graph 3*


- 1 In the **Model Builder** window, click **Point Graph 3**.
- 2 In the **Settings** window for **Point Graph**, locate the **x-Axis Data** section.
- 3 In the **Expression** text field, type `solid1.e1ogzz`.
- 4 Locate the **Legends** section. In the table, enter the following settings:

Legends
Out-of-plane strain

#### *True Longitudinal Stress (Biaxial Test)*

- 1 In the **Model Builder** window, under **Results>Material Tests (Study: Monotonic Tests)** click **True Longitudinal Stress vs True Longitudinal Strain (Biaxial Test)**.
- 2 In the **Settings** window for **ID Plot Group**, type True Longitudinal Stress (Biaxial Test) in the **Label** text field.
- 3 Locate the **Plot Settings** section.
- 4 Select the **x-axis label** check box. In the associated text field, type Strain (1).
- 5 In the **True Longitudinal Stress (Biaxial Test)** toolbar, click  **Plot**.


#### *Point Graph 1*

- 1 In the **Model Builder** window, expand the **Mean Stress vs Volumetric Strain (Isotropic Test)** node, then click **Point Graph 1**.
- 2 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.
- 3 From the **Unit** list, choose **MPa**.
- 4 In the **Mean Stress vs Volumetric Strain (Isotropic Test)** toolbar, click  **Plot**.

Add a cyclic uniaxial test for the loading sequence: tension to compression to tension.

## GLOBAL DEFINITIONS


### *Interpolation 1 (int1)*

- 1 In the **Home** toolbar, click  **Functions** and choose **Global>Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.
- 3 In the table, enter the following settings:

t	f(t)
0	0
1	2e-4
2	-1.6e-3
3	0

## SOLID MECHANICS (SOLID)

### *Cyclic Test 1*

- 1 In the **Physics** toolbar, click  **Global** and choose **Test Material**.
- 2 In the **Settings** window for **Test Material**, type **Cyclic Test 1** in the **Label** text field.
- 3 Select Domain 1 only.
- 4 Locate the **Material Tests** section. From the **Test specimen size** list, choose **User defined**.
- 5 In the  $L$  text field, type  $0.1 [m]$ .
- 6 From the **Test setup** list, choose **User defined**.
- 7 In the  $para_{max}$  text field, type **3**.
- 8 In the  $N_p$  text field, type **300**.
- 9 Find the **Tests** subsection. In the  $\lambda$  text field, type  $1+int1(para)$ .
- 10 Click **Automated Model Setup** in the upper-right corner of the **Material Tests** section.  
From the menu, choose **Set up Tests**.

Add the uniaxial stress-strain curve from the monotonic test as a reference.

## RESULTS

### *Point Graph 1, Point Graph 2*

- 1 In the **Model Builder** window, under **Results>Material Tests (Study: Monotonic Tests)>True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test)**, Ctrl-click to select **Point Graph 1** and **Point Graph 2**.
- 2 Right-click and choose **Copy**.

### *True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 1*

- 1 In the **Model Builder** window, expand the **Results>Material Tests (Study: Cyclic Test 1)** node.
- 2 Right-click **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 1** and choose **Paste Multiple Items**.


### *Point Graph 2, Point Graph 3*

- 1 In the **Model Builder** window, under **Results>Material Tests (Study: Cyclic Test 1)>True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 1**, Ctrl-click to select **Point Graph 2** and **Point Graph 3**.
- 2 In the **Settings** window for **Point Graph**, click to expand the **Coloring and Style** section.
- 3 Find the **Line style** subsection. From the **Line** list, choose **Dotted**.
- 4 From the **Color** list, choose **Black**.

### *Point Graph 3*

- 1 In the **Model Builder** window, click **Point Graph 3**.
- 2 In the **Settings** window for **Point Graph**, locate the **Coloring and Style** section.
- 3 Find the **Line style** subsection. From the **Line** list, choose **Dotted**.
- 4 From the **Color** list, choose **Black**.


### *Point Graph 1*

- 1 In the **Model Builder** window, click **Point Graph 1**.
- 2 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.
- 3 From the **Unit** list, choose **MPa**.
- 4 Locate the **Coloring and Style** section. From the **Width** list, choose **2**.
- 5 In the **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 1** toolbar, click  **Plot**.

Add a cyclic uniaxial test for the loading sequence: compression to tension.

## **GLOBAL DEFINITIONS**

### *Interpolation 2 (int2)*


- 1 In the **Home** toolbar, click  **Functions** and choose **Global>Interpolation**.
- 2 In the **Settings** window for **Interpolation**, locate the **Definition** section.

3 In the table, enter the following settings:

t	f(t)
0	0
1	-1.5e-3
2	1e-3

## SOLID MECHANICS (SOLID)

### *Cyclic Test 2*

- 1 In the **Physics** toolbar, click  **Global** and choose **Test Material**.
- 2 In the **Settings** window for **Test Material**, type **Cyclic Test 2** in the **Label** text field.
- 3 Select Domain 1 only.
- 4 Locate the **Material Tests** section. From the **Test specimen size** list, choose **User defined**.
- 5 In the  $L$  text field, type 0.1 [m].
- 6 From the **Test setup** list, choose **User defined**.
- 7 In the  $\text{para}_{\max}$  text field, type 2.
- 8 In the  $N_p$  text field, type 200.
- 9 Find the **Tests** subsection. In the  $\lambda$  text field, type 1+int2(para).
- 10 Click **Automated Model Setup** in the upper-right corner of the **Material Tests** section. From the menu, choose **Set up Tests**.

## RESULTS

### *Point Graph 2, Point Graph 3*


- 1 In the **Model Builder** window, under **Results>Material Tests (Study: Cyclic Test 1)>True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 1**, Ctrl-click to select **Point Graph 2** and **Point Graph 3**.
- 2 Right-click and choose **Copy**.

### *True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 2*

- 1 In the **Model Builder** window, expand the **Results>Material Tests (Study: Cyclic Test 2)** node.
- 2 Right-click **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 2** and choose **Paste Multiple Items**.

### *Point Graph 1*

- 1 In the **Model Builder** window, click **Point Graph 1**.

- 2 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.
- 3 From the **Unit** list, choose **MPa**.
- 4 Locate the **Coloring and Style** section. From the **Width** list, choose **2**.
- 5 In the **True Longitudinal Stress vs True Longitudinal Strain (Uniaxial Test) 2** toolbar, click  **Plot**.

